

Identification of Soil Conservation Priority Area, in Jedeb River Watershed East Gojjam Zone, Amhara Region, Ethiopia

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Abstract

Soil erosion is a major environmental problem that threatens world food production; it can be described as the removal of organic as well as inorganic soil surface materials by wind and water. This (e present) study aims to identify the most erosion vulnerable sub-watersheds for planning appropriate conservation intervention and restoration measures in Jedeb watershed. Revised Universal Soil Loss Equation (RUSLE) integrated with satellite remote sensing (RS) and geographical information system (GIS) has been applied to calculate potential soil loss at sub-watershed level. The parameters of RUSLE model were estimated using remote sensing data and ArcGIS software. The rainfall erosivity R-factor was found from 3209.6 to 3896.69 MJ.mm/ (ha.h), soil erodibility K-factor varies from 0.1 to 0.25 t ha h/ (ha MJ mm), Topographic (LS factor) ranging from 0.19 to 6.7, C-factor varies 0.01 to 0.25 and support practice P-factors from 0.1 to 1. The total annual soil loss potential of the study area was found 1,383,158 t/ yr from the total watershed area of 29,633 ha. Average annual soil loss at sub-watersheds level was estimated from 29.275 to 72.529 t/ha/year and mean annual soil loss of the entire watershed was 46t/ha/year. The study results indicated that potential soil erosion rate in the watershed was ranged into four priority categories from high to extremely severe. Three sub-watersheds covering 22.975% of the watershed shows very severe mean soil loss rate, two sub-watersheds was found severe mean soil rate which covered 19.014%, eight sub-watershed were existed under very high mean soil loss rate covers 47.59% and Three sub-watersheds were found in the high soil loss rate and covers 10.42%. Sever and extremely severe micro watersheds demand immediate attention in terms of management and planning perspective. Soil and water conservation structure was recommended and designed based on peak runoff rate, soil type, slope of the land, land use type and soil erosion hazard.

Keywords: Soil Erosion; RUSLE; GIS; Soil Conservation; Jedeb watershed; Ethiopia

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1. INTRODUCTION

Land degradation is one of the most serious ecological problems in the world (Ayad, 2009). Soil erosion is a major environmental problem that threatens world food production (Dudal, 1981). Soil is a finite and non-renewable natural resource; it takes between 200 and 1000 years for 2.5 cm of topsoil to form under cropland conditions (Pimentel et al., 1995). Fertile soils have always been the mainstay of civilizations, and great civilizations have fallen in the past because they failed to prevent the degradation of soils on which they survived (Diamond, 2005). Soil erosion has negative effects on the standard of living of the inhabitants, especially in developing countries like Ethiopia, where agriculture is considered as the main source of peoples' income and food (Hurni, 1993). It is the most serious form of land degradation, in which its on-site and off-site effects threaten the food security and the national economy of the country (Hurni, 1993; Sutcliffe, 1993; Lulseged and Vlek, 2005).

Jedeb river watershed is characterized by a serious soil erosion problem inducing heavy silt loads in rivers and reservoirs. The area is severely degraded and decreased crop productivity from year to year because the area is rugged topography prone to soil erosion and easily eroded due to deforestation and poor agricultural practice. Off-site effects of soil erosion are also the major negative environmental externality affecting the welfare of the rest of the society in the area. In the watershed, sheet and inter rill erosion, gully formation and exposed surfaces for erosion on steep slopes is the most visible evidence to show erosion problem. Soil fertility is declining fast in the upstream and midstream due to severe soil erosion, continuous cultivation, up and down farming and removal of crop residue. The watershed is still subjected to agricultural use without conserving natural resources.

To undertake corrective measures and prevent further degradation of many watersheds, timely information on the extent and spatial distribution of erosion areas is paramount importance. This information is necessary for cost effective soil conservation planning and implementing. To solve this problem it was necessary to estimate rates of soil loss and develop a soil loss intensity map of the study watershed using RUSLE within a GIS environment, identify severity areas and prioritize areas for specific soil conservation plans. On the basis of the information generated designing and recommendation of soil conservation measures are needed to be adopted for watershed development programs.

Now a day different scientific models are used worldwide to study watershed management. Several soil erosion models exist with varying degrees of complexity. One of the most widely applied empirical models for assessing the sheet and rill erosion is the Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith(1965) and Revised Universal Soil Loss Equation (RUSLE) model can predict erosion potential on a cell-by-cell basis (Shinde *et al.*, 2010). Other soil erosion models range in various degrees of complexity, models like EUROSEM (European Soil Erosion Model), ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation), CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems), and MODANSW (modified ANSWERS), are basically conceptual and event based models. Using conventional methods to assess soil erosion risk is expensive and time consuming (Jha and Paudel, 2010). The choice for a particular model largely depends on the purpose for which it is intended and the available data, time and money (Lal, 2001). The Universal Soil Loss Equation (USLE) and its revised version RUSLE are two of the empirical models that have been most widely used and generally accepted by the natural resources community because they are relatively easy to use and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Saavedra, 2005). Due to this reason Universal Soil Loss Equation (USLE) was used in this study. The objectives of the present study are made: (1) To estimate potential soil loss in the study area using RUSLE model; (2) To identify high erosion risk areas (erosion hotspots) in the watershed, and (3) To design and recommend appropriate soil and water conservation measure.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Location of the study area

Jedeb watershed is located in East Gojjam zone of Amhara Regional State, North Western Ethiopia. The watershed encompasses three districts Sinen, Machakel and Gozamin. Jedeb watershed is found about 20 km from Debre markos and 320 km from Addis Ababa. Runoff from this watershed drains in to Blue Nile River. The watershed has an area of 29,633 hectare, and is geographically located between 10°20' -10°40'N latitude and 37°35' -37°50'E longitude.

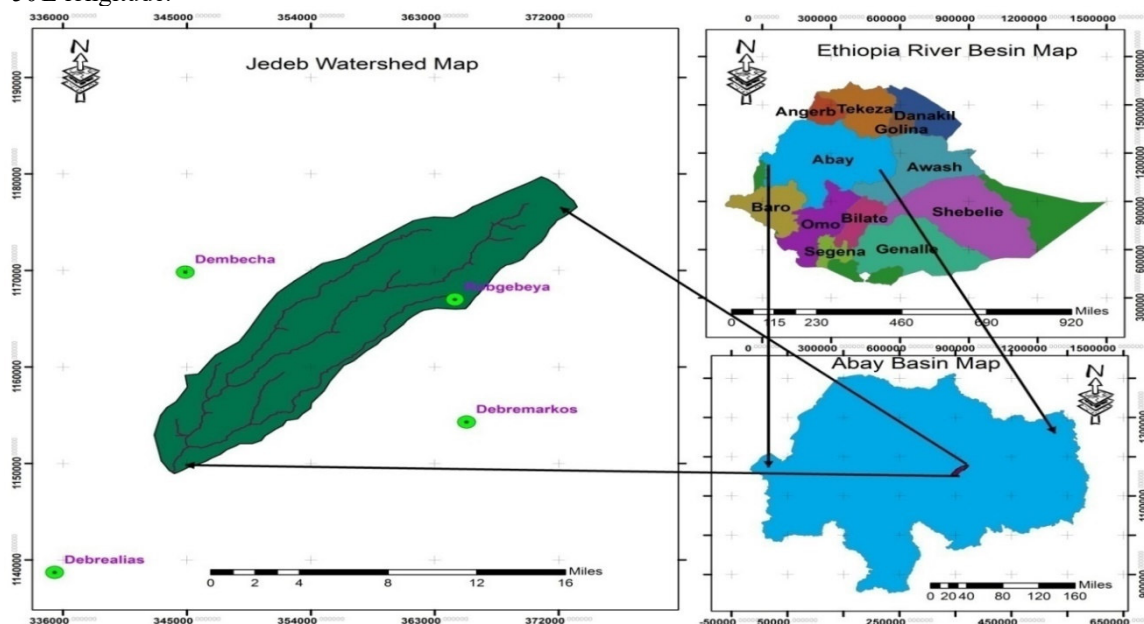


Figure 1. Location map of Jedeb watershed

2.1.2. Climate

The mean annual precipitation ranges from 1240.6-1389.8 mm. Jedeb watersheds can be divided in to rainy and dry seasons. The rainy season extends from June to September. Mostly the dry season occurs between January to March and the remaining months have got partially rain. Long term average minimum and maximum temperature of the study area varies between 12°C-22°C.

2.1.3. Soil, land use and topography of study area

The soil types of the area are Eutric Cambisols, Eutric Leptosols, Haplic Alisols, Haplic Luvisols, and Mollic Luvisols. The study area is mostly dominated by Haplic Alisols with 42.5% and Haplic Luvisols with 26.5% out of the total watershed. The area was a mountainous and highly dissected terrain with steep slopes characterizes in the midstream and upstream part, but the downstream part has undulating topography and relatively gentle slopes and elevation of the study area ranges from 2146 -3978 m.a.s.l. The land use practice of the study area includes grass land, cultivated land, forest land, afro-alpine, wetland, and shrub and bush land. The dominant land use type

in the study area was cultivated land which covers about 86 % from the total watershed.

2.2. Methods

The input thematic data included rainfall, soil units, slopes and land use/cover and determined as follow.

2.2.1. Determination of Soil Loss Factors

The soil erosion assessment was estimated under ArcGIS environment using Revised Universal Soil Loss Equation (RUSLE) model. The five erosion factors, rainfall erosivity (R), soil erodibility (K), slope steepness- length (LS), cover management (C) factor and conservation practice (P) were estimated and used for the estimation of average annual soil loss. Annual soil loss rate was determined by a cell-by-cell analysis of the soil loss surface by superimposing and multiplying the RUSLE factor values (R, K, LS, C and P) by using “Raster Calculator under Map Algebra of Spatial Analyst Tool” in Arc GIS 10.1. The soil loss intensity map was prepared for ease of interpretation. This soil loss map was overlaid with 16 sub-watershed map of Jedeb watershed to get sub-watershed wise soil loss. All the five factors were multiplied by applying the following equation in Arc GIS10.1 using raster calculator (Renard et al., 1997).

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (1)$$

where: - A = spatial average soil loss rate (t/ha /year), R = rainfall-runoff erosivity factor [MJ mm/ (ha h year-1)], K = soil erodibility factor [t ha h/ (ha MJ mm)], L = slope length factor S= slope steepness factor, C = cover management factor, and P = conservation support practice factor.

2.2.1.1. Rainfall erosivity factor (R)

Rainfall erosivity factor of the watershed was calculated on the bases of mean annual rainfall data of each station by using the regression equation developed for upper Blue Nile River in Amhara region where rainfall intensity data is not available (Tewodros *et al.*, 2014).

$$R = -0.0058(p)^2 + 19.86p - 12502 \quad (2)$$

where: R = rainfall erosivity factor, and

P = mean annual rainfall in mm

In order to compute R factor, four metrological stations (Debre markos, Dembecha, Debre alias and Rebugebeya) with 24 years rainfall data (1992-2015) were used. After having the daily rainfall data of each meteorological station mean annual rainfall (P) of each station was calculated. Based on mean annual rainfall data, the erosivity factor (R) of the study area was calculated. By using Thiessen Polygon method the mean annual rainfall were interpolated in ArcGIS10.1 to produce rainfall erosivity map.

$$\bar{P} = \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 + \dots + P_n A_n}{A_1 + A_2 + A_3 + \dots + A_n} = \frac{\sum_{i=1}^n P_i A_i}{\sum_{i=1}^n A_i} \quad (3)$$

where \bar{P} = the weighted average

P's = rainfall amount recorded at different station

A's = areas of each polygon.

2.2.1.2. Soil erodibility factor (K)

In this study, the soil map of the study area was obtained by clipping the soil data with watershed boundary in ArcGIS environment. In the adaptation of RUSLE to Ethiopian considers the soil type to have relation with erodibility even though others consider soil texture and structure so as to determine the value of soil erodibility factor. Five soil types were identified in the study area (Eutric Cambisols, Eutric Leptosols, Haplic Alisols, Haplic Luvisols and Mollic Luvisols). The erodibility value was obtained from the soil type of the study area generated by ArcGIS 10.1 and the corresponding K-value were referred from (FAO, 1989). The map of K values was generated to show spatial distribution of soil erodibility. After that the resulting shape file was changed to grid file or raster form having 30*30 meter cell size after assigning K values for each soil types. The raster map was then reclassified based on their erodibility value.

2.2.1.3. Topographic factor (LS)

For this study, digital elevation model (DEM) 30m resolution was extracted by mask in the ArcGIS environment to encompass the zone of interest and used for generating LS factor. The method for computing LS requires a flow accumulation grid layer and slope grid layer. Flow accumulation grid represents number of grid cells that were contributed for the downward flow. Establishing the dominant slope length was difficult because the need to separate each segment of slope and the possibility not being able to identify shorter and flat slopes. Therefore, slope length combined with slope gradient factors was determined by SCRP (1997) for Ethiopian conditions. The raster layers of slope% was generated and reclassified according to the slope SCRP class using spatial analysis tool in ArcGIS 10.1 interface (Table 1). The output layer of the LS value was assigned for each slope class.

Table 1. Combined slope gradient and slope length LS factor

Slope (%)	<2	2-4	4-6	6-8	8-13	13-25	25-40	40-55	55-100	>100
LS-factor	0.19	0.38	0.66	1.14	1.90	3.80	6.08	7.98	10.45	19.00

Source: Adopted from SCRP for Ethiopian condition (cited by Abbey, 2010 and Israel, 2011)

2.2.1.4. Land use/cover (C)

For the study area, land-use and land-cover map was prepared from LANDSAT satellite image, Path 169 and Row-053. The required data, Land Sat images were downloaded from internet which is freely available for everybody. The land use/land cover classes to be considered in the image classification process were identified. This was done by using field survey and visual image interpretation of the source image. For this study supervised land use and land cover classification were undertaken by ERDAS10 software. The accuracy assessment of the land use and land cover maps has been undertaken by comparing the field data collected by GPS with the classified images in ERDAS 10 software. The land use/cover factor was estimated by using the land use/cover map as an input. From the Supervised digital image classification method six land-use and land-cover classes were recognized. These include grazing land, cultivated land, forest land, afro-alpine, wetland, and bush land. The cover (C) factor corresponding to each land use land cover was estimated from different literature listed in Table 2. A corresponding C-value was assigned to each land use class using the “reclass” method in ArcGIS 10.1. The cover (C) factor of each land use/ cover was assigned from different literature. Then the value was changed to raster by conversion tool method from feature to raster.

2.2.1.5. Land management practice (P)

Erosion control practice factor (P-factor) is the ratio of soil loss with a specific support practice to the corresponding loss with up slope and down slope cultivation. According to Wischmeier and Smith (1978) the land is delineated in to two major land uses, agricultural and non-agricultural land for management practice. Thus, the agricultural land was classified into six slope categories and assigned P-values; while all non-agricultural land was assigned a P-value of 1.00. The slope and land use/cover maps were intersected spatially in ArcGIS10.1 and assigned a p-value. The assigned P-value was changed from feature to raster under conversion tools in ArcGIS 10.1.

2.3. Sub-watershed Prioritization

Prioritization of sub-watersheds was done on the basis of average annual soil loss. Generation of sub-watershed wise soil loss was done by extraction in spatial analysis tool in ArcGIS 10.1. Prioritization of sub-watersheds involves ranking of the different sub-watersheds according to the order in which they ought to be taken up for treatment with conservation technologies by considering the amount of soil loss.

2.4. Designing and Recommendation of Soil and Water Conservation Measures

The primary function of soil conservation structures is to control runoff water by intercepting it and transferring it safely into the local drainage network. Firstly, an estimate was made peak runoff rate that the structure was required to accommodate. An estimate of runoff volumes was required when a water storage structure such as a pond was designed. Secondly different structures were designed to carry and store the expected runoff discharge for an event with a chosen average recurrence interval.

In this study, peak runoff rate was estimated by using Rational Method. Rational formula estimates the peak runoff rate at any location in a catchment area as a function of the catchment area, runoff coefficient, and rainfall intensity for duration equal to the time of concentration

The Rational formula is expressed as:

$$Q = \frac{1}{360} CIA \quad (3)$$

where: Q = design peak discharge (m³/sec), C= runoff coefficient representing a ratio of runoff to rainfall, I = average rainfall intensity for aduration equat to the Tc, for a selected return period (mm/hr), A= the watershed area (ha)

Watershed area:-The first step in applying the Rational Method is to obtain a good topographic map and define the boundaries of the catchment area. A field inspection of the area was done to determine the natural drainage divide line has been altered.

Time of concentration:-The time of concentration (Tc) is the time at which the entire watershed begins to contribute to runoff. This is calculated as the time taken for runoff to flow from the most hydraulically remote point in the In this study, the time of concentration was computed by Kirpich’s equation.

$$T_c = 0.0195L^{0.77}S_g^{-0.385} \quad (4)$$

where: T_c = Time of concentration (hr),

L = Length of the main water course (m),

S = slope of the main water course (m/m)

Runoff coefficient:- The runoff coefficient (C) is a function of ground cover and host of other hydrological abstraction. The value of runoff coefficient (C) under different conditions is given in Appendix Table 1. To decide the C value of an area, it is vital to explore and analyze the topography, vegetation cover and soil type.

Bund spacing:- It is the distance between two bunds, as the water flows through a sloping land, it attains erosive velocity. Spacing of bund was calculated on the base of elevation deference and gradients of the area

Runoff coefficient:- under different conditions is given in Appendix Table 1. To decide the C value of an area, it is vital to explore and analyze the topography, vegetation cover and soil type.

Velocity of flow:- The velocity flow is referred to as maximum allowable velocity or permissible velocity. In this study velocity of flow was calculated by using manning's equation.

$$V = (R^{2/3} S^{1/2}) / \eta \quad (5)$$

R = hydraulic radius,

S = bed slope m/m,

η = Manning roughness coefficient

Bund spacing:- As the water flows through a sloping land, it attains erosive velocity. The bund should be spaced in such a way so as to intercept the erosive velocity. Again, the spacing should not be too close to interfere with the farming operations. Spacing of bund was calculated on the base of elevation deference and gradients of the area.

$$HD = \frac{VI}{S} * 100 \quad (6)$$

where

HD = Horizontal distance between two bunds

VI = vertical interval between consecutive bunds [m], and

S = land slope [in per cent].

Vertical interval was calculated by Ramser's Formula. Ramser conducted experiments in sub-humid areas and developed the following relationship for vertical interval between two bunds.

$$VI = 0.3 \left(\frac{S}{3} + 2 \right) \quad (7)$$

3. RESULTS AND DISCUSSION

3.1. Rainfall Erosivity Factor (R)

Figure 2 shows the spatial distribution of rainfall erosivity values throughout the watershed. The erosivity values of the study area were in the ranged of 3209.6 MJ.mm/ (ha.h) to 3896.69 MJ.mm/ (ha.h). From this result, the smaller R-factor was found in the downstream part of the study area indicating that this part of the study area was less vulnerable to erosion where as the upstream part of the study area was more vulnerable to erosion (Figure 2). In general, rainfall erosivity values increased from southwest to northeast part of the watershed depending on precipitation characteristics.

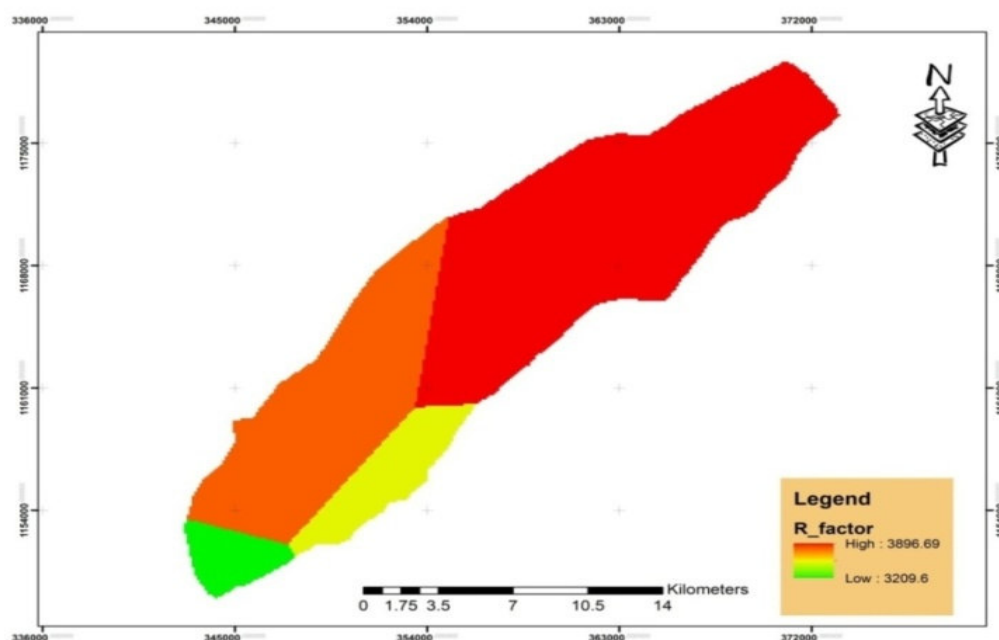


Figure 2. Rainfall erosivity map of Jedeb watershed

3.2. Soil Erodibility Factor (K)

As shown in (Table 2), the high k-factor value indicates more vulnerable soil type to soil erosion and the lower value shows less vulnerable soil type to soil erosion. The high K-factor value was shown in Haplic Alisols which was found in the lower side of the watershed and the lower K-factor value was shown in Mollic Luvisols which was found in the upper part of the watershed. This indicates that Haplic Alisols have higher soil erodibility, while the Mollic Luvisols have relatively lower soil erodibility. This implies that the Mollic Luvisols were more resistant to erosion because of their low detachability; while the Haplic Alisols were more susceptible to soil erosion and the remaining soil type indicated in (Figure 3) have moderate soil erosion under similar conditions that affect soil loss. Finally, the results indicated that soil erodibility value in the study area was estimated to be in the range of 0.1 to 0.25 (Figure 3).

Table 2. Soil type and erodibility coverage

No	Major soil types	Area (ha)	Area (%)	K factor value
1	Eutric Cambisols	165.10	0.55	0.15
2	Eutric Leptosols	7642.75	25.79	0.20
3	Haplic Alisols	12581.03	42.45	0.25
4	Haplic Luvisols	7856.29	26.50	0.20
5	Mollic Luvisols	1387.85	4.70	0.10

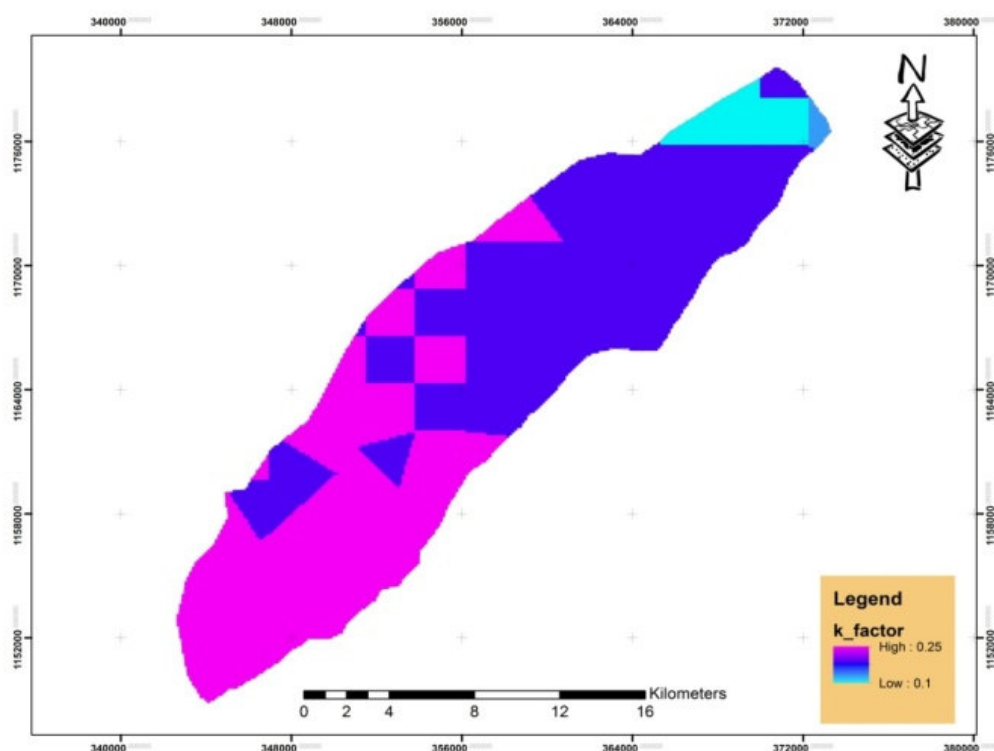


Figure 3. Soil erodibility map

3.3. Topographic Factor (LS)

According to the analysis, the LS factors of the watershed were found in the range of 0.19 to 19. The highest value of LS was distributed in the steep mountainous terrain and the lowest value of LS was distributed in gently flat to undulating terrain. As shown in Figure 4, the smaller value of LS factor was found in the downstream part of the study area. This part of the watershed indicates that less vulnerable to erosion and the higher value which was found in the midstream and upstream part of the study area showing high LS factor and therefore, highly sensitive to soil erosion.

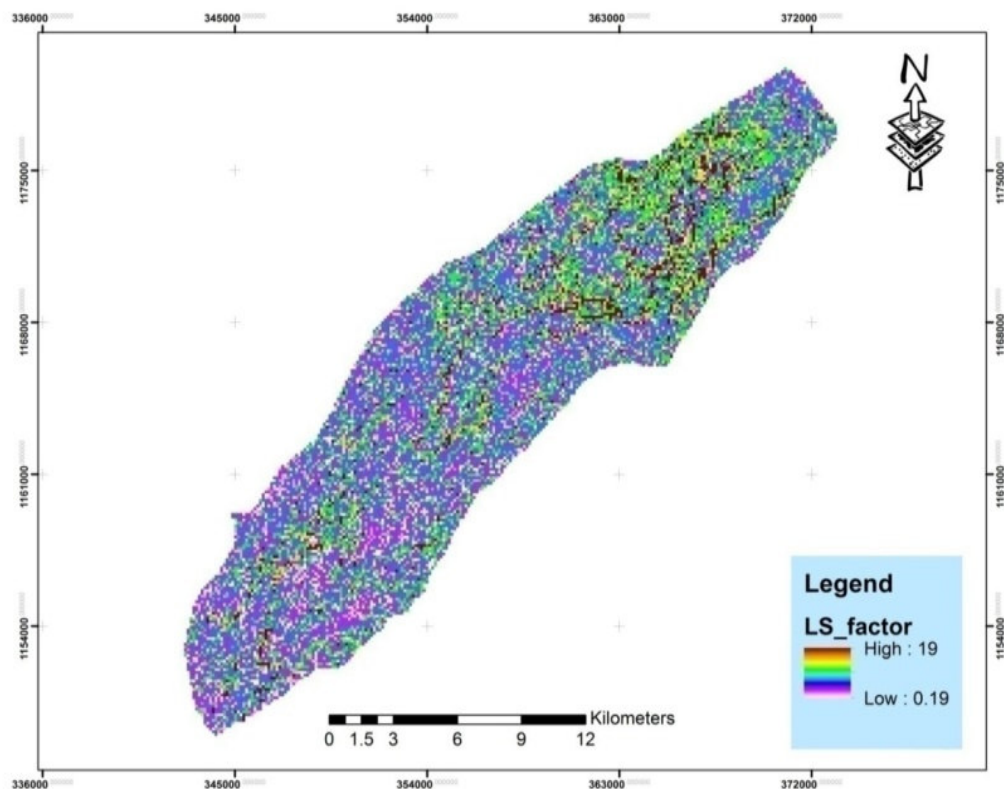


Figure 4. Slope length and steepness (LS) factor distribution in the study area

3.4. Land use/cover (C)

As shown in Figure 5, the value of C-factors were found ranging from 0.01– 0.25 which was estimated from different literatures. Based on the analysis the larger value shows more vulnerable land use to soil erosion and on the other hand the lower value shows less vulnerable land use for erosion. From this result cultivated land had a large value of C-factor (0.25) which was highly vulnerable to erosion. Wetland and Afro-alpine having the c-factor 0.01 was less susceptible to erosion.

Table 3. Crop factor of the study area

No	Land use	Source	Cover factor/ C-value/	Area (ha)	Area (%)
1	Cultivated land	Hurni, 1985	0.25	25411.40	85.75
2	Forest	Hurni, 1988	0.02	1763.35	5.95
3	Afro-alpine	BCEOM, 1998	0.01	615.71	2.08
4	Grass land	Hurni, 1985	0.05	1478.77	4.99
5	Shrub and bush land	BCEOM, 1998	0.06	310.35	1.05
6	wetland	BCEOM, 1998	0.01	53.49	0.18
Total				29633.00	100.00

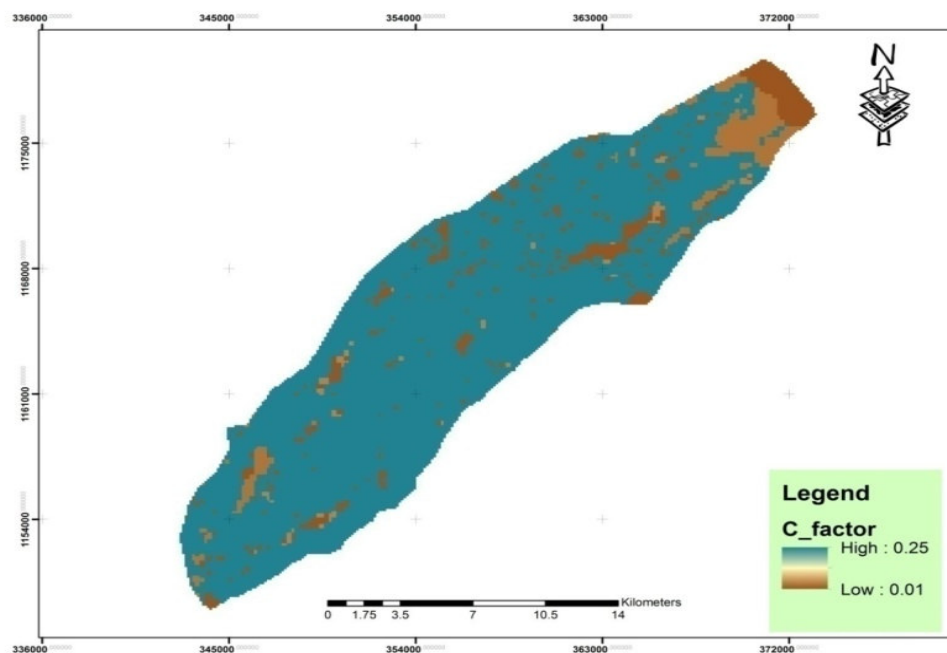


Figure 5. Map showing distribution of C-factor in Jedeb watershed

3.5. Land Management Practice (P)

The results indicated that the distribution of P-factor ranges from 0.1 to 0.43 in the cultivated land and 1 for other land use in. The assigned P-value was changed from feature to raster under conversion tools in ArcGIS 10.1. The highest P-value of the watershed was found in upstream part of the study area, but the smallest value was indicated in the downstream and midstream part of the watershed (Figure 6). These implies P indicates the effect of conservation practices on soil erosion, wherein the land which has adequate conservation interventions. Therefore, soil and water conservation intervention is less in the upper parts of the watershed. The P factor value decrease by adopting the conservation practice factor.

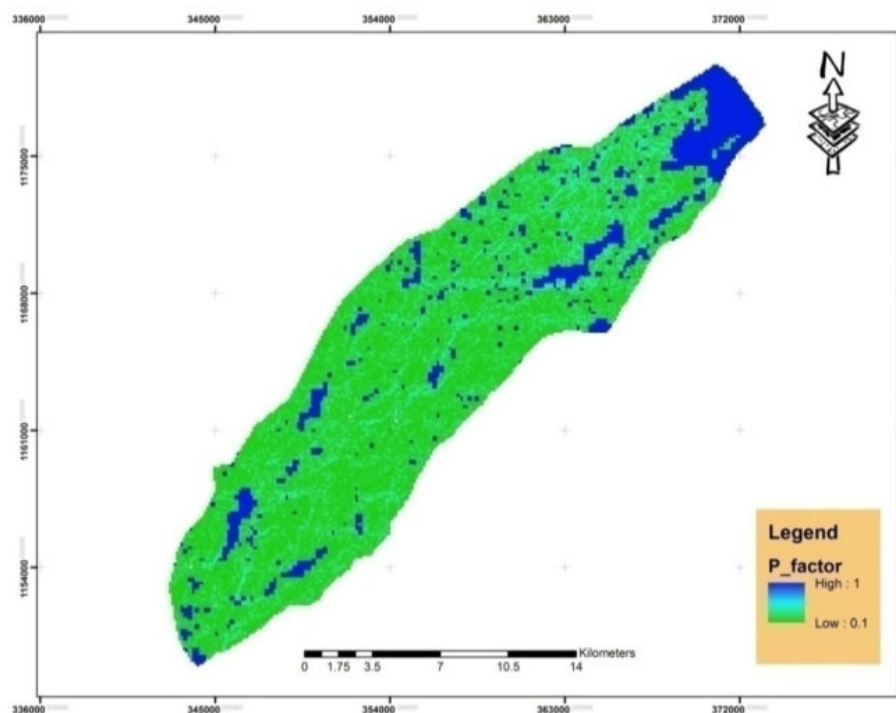


Figure 6: Land management factor (P) values

Table 4. Land Management Factor (P) values

Land use type	Slope (%)	P factor	Area	
			hectare	percent
Cultivated land	0-5	0.1	1352.35	4.56
	5-10	0.12	3488.14	11.77
	10-20	0.14	8670.71	29.26
	20-30	0.22	5634.05	19.26
	30-50	0.31	4667.22	15.75
	50-100	0.43	1598.91	5.40
Other land use	all	1	4221.63	14.25
Total			29633.00	100.00

3.6. Potential Soil Loss in the Watershed

Based on the analysis, the result indicate that the potential annual soil loss had been ranged from 0 t/ha/ yr in the downstream plain area of the watershed to 289.7 t/ha/ yr in midstream and upstream parts of the study area. This was due to high rainfall, steep slope and poor vegetation cover of the study area. The total annual soil loss potential of the study area was found 1,383,158 t/ yr from the total watershed area of 29,633 ha. Average annual soil loss for the entire watershed was estimated at 46 t/ha/yr, which is much greater than the tolerable level 11 t/ha/yr (Renard *et al.*, 1997). The estimated soil loss rate and spatial pattern were generally realistic, compared to results from previous studies in other area. According to FAO (1984), the annual soil loss of the highlands of Ethiopia ranges from 1,248 – 23,400 million ton per year from 78 millions of hectare of pasture, ranges and cultivated fields throughout Ethiopia, which is equivalent to 16 to 300 t/ha/ yr. In 5 years of monitoring in a nearby experimental micro-watershed (the Anjeni) located 35 km northwest from the study area, soil erosion from cultivated fields under the traditional land-use practices ranged from 17 to 176 t/ha/ yr (Herweg and Ludi, 1999). FAO (1986) estimated average soil loss from croplands in the highlands as a whole at 100 t/ha/ yr. The result of this study falls within the ranges of the above findings. Based on the estimated annual soil loss rates, the values of soil loss were divided into seven classes using FAO (1986). From these result (Table 5), one third of the watershed (33.39 per cent) was predicted to suffer from a severe to extreme severe erosion risk which is found in the midstream and upstream parts of the watershed where steep lands had been cultivated, high rainfall area and overgrazed. In the midstream part of the watershed, it was observed the highest erosion damage area. Thus the extremely severe and very severe class shows relatively more vulnerable and the low and medium class shows less vulnerability to soil erosion.

Table 5. Different soil erosion intensity class

No	Soil loss rate (t/ha/ yr)	Severity class	Area (ha)	Area (%)
1	0-10	Low	3204.91	10.82
2	10-20	Moderate	5410.12	18.26
3	20-30	High	5237.23	17.67
4	30-45	Very High	5913.60	19.97
5	45-60	Sever	2382.53	8.04
6	60-80	Very severe	2822.11	9.52
7	>80	Extremely sever	4662.50	15.73
Total			29633.00	100.0

Source: Erosion class of (FAO, 1986)

Figure 7 shows the spatial locations of the hot spot area for soil erosion in the study revealed that the potential soil loss was typically greater along the steeper slope and high rainfall areas. Other high soil erosion areas were dispersed throughout the watershed and had been typically associated with high erosion potential land uses. In midstream and upstream part of the watershed most of the cultivated land was situated on steep slope areas. Since crop cultivation in the watershed practiced without implementing any soil and water conservation measures, cultivated lands were the major soil erosion risk areas. Soil erosion in agricultural fields affects not only land productivity but also water bodies in the downstream.

Generally removal of vegetation cover through deforestation, cultivation of steep slope, overgrazing, ploughing the land several times, the practice of removing plant residues, poor physical soil and water conservation measures can cause for high soil loss in the study areas.

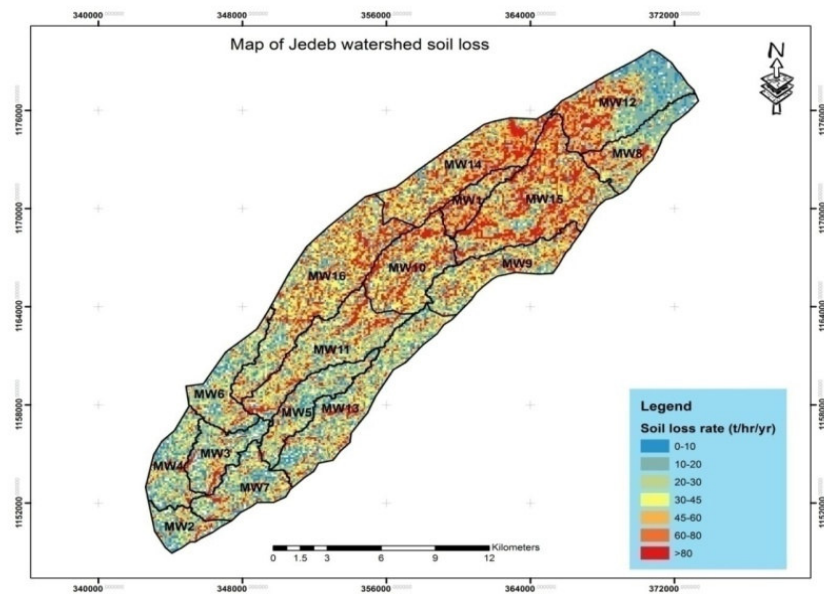


Figure 7. Soil loss intensity distribution map of Jedeb watershed

3.7. Prioritization of Sub-watersheds

In order to determine which area of the watershed with high risk of erosion for prioritization of intervention, the study watershed was classified into 16 sub-watershed based on their drainage pattern. The soil loss values for each of the sub-watershed were extracted from the soil loss map of Judeb watershed and mean soil loss value for each sub-watershed was obtained as shown in Table 6. Some sub-watersheds may get highly vulnerable to soil erosion due to various reasons. All the 16 sub-watersheds in the study area were prioritized by considering the results of various thematic maps derived from satellite imagery as well as rainfall and soil data. According to mean annual soil erosion rate sub-watershed were ranked as indicates in the Table 6. As table 6 shown that the maximum mean annual soil loss was occur at the SW 15 which is 72.529tons ha⁻¹year⁻¹ which covers 26.296 km² from the total area of watershed but the maximum soil loss occurs at the SW4 29.275tons ha⁻¹year⁻¹ which covers 11.346km² from total watershed area. These implies that SW15 must be prioritize for soil and water conservation strategies and SW4 has less prioritize for soil and watershed practice planning process.

Table 6. Ranked sub-watersheds based on mean annual soil loss

Sub-watershed	Area(ha)	Area in km2	Area (%)	Gross mean soil loss (t/ha/yr)	Sediment delivery ratio	Sediment yield (t/ha/yr)	Rank (priority)
SW-1	988.64	9.886	3.336	59.530	0.630	37.50	2
SW-2	995.34	9.953	3.359	29.966	0.632	18.94	11
SW-3	1085.84	10.858	3.664	34.215	0.620	21.21	10
SW-4	1134.64	11.346	3.829	29.275	0.615	18.00	15
SW-5	1268.84	12.688	4.282	29.979	0.602	18.05	14
SW-6	1299.97	13.000	4.387	30.237	0.598	18.08	13
SW-7	1320.47	13.205	4.456	33.380	0.596	19.89	12
SW-8	1462.16	14.622	4.934	37.890	0.585	22.17	9
SW-9	1780.78	17.808	6.009	44.608	0.560	24.98	5
SW-10	2026.03	20.260	6.837	58.630	0.548	32.13	4
SW-11	2387.76	23.878	8.058	44.190	0.530	23.42	6
SW-12	2451.24	24.512	8.272	43.620	0.527	22.99	7
SW-13	2513.54	25.135	8.482	33.676	0.524	17.65	16
SW-14	2579.91	25.799	8.706	70.180	0.522	36.63	3
SW-15	2629.57	26.296	8.874	72.529	0.520	37.72	1
SW-16	3708.27	37.083	12.514	46.480	0.485	22.54	8

According to soil erosion severity class FAO (1986) the result of mean annual soil loss rate in the sub-watersheds were indicated in four severity classes as shown in the Table 7. Name was given as high, very high, severe and very severe soil erosion intensity class. Thus very severe and severe class's shows relatively more vulnerable and high severity class shows less vulnerable class for soil erosion than the other class and relatively low mean annual soil loss.

Table 7. Classification of Sub-watershed based on soil loss intensity

Severity class	Mean soil loss rate(ton/ha/ yr)	Sub_watershed	No. of Sub-watershed	Area (ha)	Area (%)
Low	0-10				
Moderate	10-20				
High	20-30	5,2,4	3	3088.82	10.424
Very high	30-45	9,11,12,8,3,13,7,6	8	14101.76	47.588
Severe	45-60	.10,16	2	5634.30	19.014
Very severe	60-80	15,1,14	3	6808.12	22.975
Extremely severe	>80				
Total			16	29633.00	100.00

Source: Erosion class of FAO, (1986)

As shown in Table 7 out of the 16 sub-watersheds, three sub-watersheds (SW-15, SW-1, and SW-14) were observed in very severe soil loss rate due to high contribution of rainfall erosivity, land use practice and LS factors. In severe erosion classes there are two sub-watersheds (SW-10 and SW-16) which are spatially located at the midstream part of the Journal of Soil Science and Environmental Management watershed with mean annual soil loss ranging from 46.48 to 58.63 t/ha/ yr due to high contribution of erosivity, C-factor and LS factors. The largest portion (47.59%) of the sub-watershed were existed under very high erosion classes which are found in the downstream and upstream part of the watershed and eight sub-watershed fall in this range (SW9, SW11, SW12, SW8, SW3, SW13, SW7 and SW6) with mean annual soil loss between 30.24 to 44.61 t/ha/ yr. About 10.42% of the watersheds (SW-5, SW-2 and SW-4) were found in the high erosion classes, located in the lower part of the study area.

In general mean soil loss intensity map in Jedeb sub-watershed (Figure 8) clearly shows that nearly the entire watershed requires implementation of different types of soil and water conservation measures for a sustainable land use depend on their order. Based on the annual soil losses, erosion vulnerable sub-watersheds were identified and ranked in ascending order.

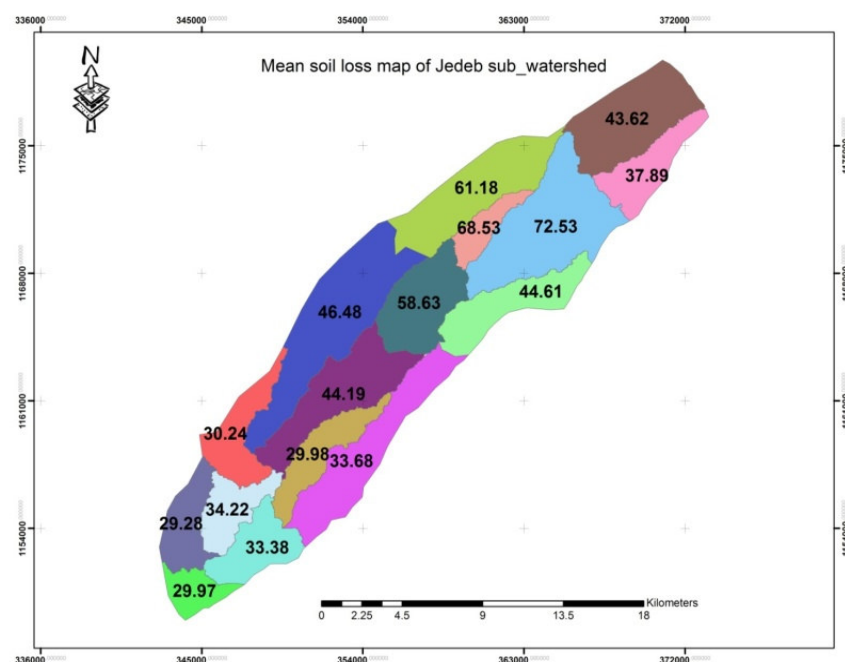


Figure 8: Mean soil loss intensity in Jedeb sub-watershed

4. CONCLUSION AND RECOMMENDATIONS

The preset study was to identify the most erosion vulnerable micro-watersheds for planning appropriate conservation intervention and restoration measures. The model used to calculate average annual soil loss was the Revised Universal Soil Loss Equation (RUSLE). Thus RUSLE model integrated with satellite remote sensing and geographical information systems had provided useful information for the assessment and decision-making about the vulnerability of sub-watersheds for undertaking required conservation measures. Based on the analysis, total annual soil loss potential of the study area was found to be 1,383,158 t/ yr from the total watershed area of 29.633 km². The regional soil erosion risk map shown that, the average annual soil loss was found 46 t/ha/ yr in the watershed, and the spatial distribution of erosion risk classes was 10.42% high, 47.58% very high, 19% severe,

and 22.97% very severe. The result map of the cell to cell multiplied parameter layers show that the study area had significant levels of soil loss estimation that varies from about 0.00 to plain areas and 289.7 t/ha/ yr on steep slopes. This estimated soil loss for the study area is within the range of soil loss estimated for the Ethiopian highlands by FAO (1984) which ranges from 1,248 – 23,400 million ton per year from 78 millions of hectare of pasture, ranges and cultivated fields throughout Ethiopia, which is equivalent to 16 to 300 t/ha/ yr. The important results of the study include soil erosion hazard map of the watershed and the prioritization of sub-watersheds into conservation priority categories, which can be used for preparation of a conservation plan for management of the watershed. The results from the soil erosion risk map show that the soil erosion risk was higher in the midstream part of the watershed than upstream and downstream part of the area. The outcome would help to provide options for governmental and non-governmental organizations who work on environmental protection and other related issues during planning and implementation of soil and water conservation measure. Sub-watershed categorized under severe and extremely severe soil erosion rate should be given special priority to reduce or control the rate of soil erosion.

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